

**United States Military Academy  
West Point, New York 10996**

**Land Warrior Power Management**

**OPERATIONS RESEARCH CENTER OF EXCELLENCE  
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## **Abstract**

The Soldier Tactical Mission System (STMS) requires power to operate – power that must be carried by the soldier. As the system becomes more advanced the power usage of each component is diminished, while the power carrying capacity, in terms of duration, improves. This improvement is incremental; yet the goal of power management for this system is to significantly increase the length of time a single source can supply the system with power without resupply.

In order to develop a power management architecture for the system it is necessary to ascertain what components, under specified conditions, provides the most utility to the soldier. After this is done tradeoffs can be made and, under conditions of restricted power supply, decisions can be made to turn off components that are less beneficial. Determining the utility of those components is the focus of this report. We examine the STMS with the use of complexity theory and combat simulations based upon Agent Based Models, developing a conceptual framework with to analyze the components. Further work needs to be done to analyze the system in various scenarios, specified in the Operational Requirements Document, to obtain the utilities described above.

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## **Chapter 1: Introduction**

The Soldier Tactical Mission System (STMS) has the potential to change the way the dismounted infantry soldier fights. The STMS is information centric, and the system provides near real time situational awareness to the soldier on both the friendly and enemy situation. These gains will allow soldiers to have a better understanding of the battlefield and therefore will allow them to make better decisions.

Combat simulations, on the other hand, are for the most part lacking in situational awareness for automated decision making. Though many incorporate the information flow on the battlefield, they lack a mechanism for this information to influence the battle. Humans in the loop in many of these simulations account for this decision making, and while that is beneficial from a training standpoint it is often difficult to analyze equipment based upon the abilities of just a few people having access to the simulation, and it is not possible to generate statistically significant data on the usage of that information.

This report is in the form of a compilation of papers. Chapter Two is a paper that discusses the power problem in general and talks to both decision architecture solutions and technical solutions. This paper was published in the proceedings of the American Society of Mechanical Engineers International Solar Energy Conference Proceedings and was briefed by Dr. Margaret Bailey at that conference in March of 2003 in Honolulu, Hawaii. Chapter Three is a paper that discusses the modeling of the system utilizing Agent Based Models and the results obtained from that analysis. This paper was published in the IEEE Systems and Information Engineering Proceedings and was briefed by the authors in Charlottesville Virginia in April of 2003. Chapter Four discusses conclusions and the way ahead for this research.

## **Chapter 2: International Solar Energy Conference Paper**



## Meeting Military Energy Demands

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### ABSTRACT

The United States Army's Soldier Tactical Mission System is capable of providing a dramatic change in small-unit warfare with its enhanced communications, situational awareness, and navigation capabilities. A significant drawback to this system, however, is that the very systems that provide these advantages to the soldier also demand high quantities of energy. In order to design an adequate energy delivery system to support the operation of the soldier's enhanced equipment, the problem is broken down and analyzed into three general areas: energy demand, energy management, and energy source design. The aim of this paper is to introduce the reader to each of these three general areas, thereby providing a potential catalyst for future research and exploration into the design solution of adequate energy delivery systems.

### KEYWORDS

Photovoltaic, thermoelectricity, batteries, energy demand, modeling, soldier systems, military, energy source, microturbines, fuel cells, and energy management

### INTRODUCTION

Using today's available energy source and storage technologies, increased soldier energy demand translates into increased demand for batteries, representing a logistically difficult solution. Alternative solutions are currently being investigated by research teams throughout the country through

the investigation of alternative energy source and storage systems as well as advanced energy management schemes. At the United States Military Academy at West Point, New York, officers, cadets, and civilian professors are studying this problem and proposing solutions.

The Land Warrior is the first full production version from the United States Army's Soldier Tactical Mission System (STMS). A soldier equipped with the Land Warrior system is shown in Figure 1.



Figure 1 - A soldier equipped with the Land Warrior system. The Land Warrior is the first full production

## version from The United States Army's Soldier Tactical Mission System (STMS).

Under development by the United States Army, the Land Warrior system has the potential to dramatically change the conduct of warfare. With this equipment, soldiers will have greatly increased and significantly more accurate knowledge of their surroundings. The Land Warrior system will incorporate a wireless local area network, global positioning, and other technologies to provide the soldier with situational awareness that provides an accurate picture of friendly positions, intelligence on enemy positions, terrain, et cetera. The soldier will also have communications capabilities that have never been available. The soldier can send audio, typed, and drawn messages to fellow soldiers via the wireless local area network, and commanders can communicate orders to their subordinates using these capabilities thus greatly speeding up operations and enhancing understanding. The Land Warrior system will also incorporate new weapon capabilities. The Land Warrior equipped soldier will be able to fire from protected positions with the video sight or other sensors mounted on the rifle. The capabilities that the Land Warrior system will provide the American Soldier will afford enormous advantage to the United States Army.

Energy source solutions for the Land Warrior are state-of-the-art today. Viable energy sources must maximize energy density (the amount of energy measured in kWh/kg), be submersible in one meter of water while remaining operational, and be constructed rugged enough to endure air drops and a combat environment. The energy source must also be user friendly, placing no additional burden on the soldier during normal use or replacement. Possible energy sources include fuel cells, batteries, micro-turbines, photovoltaic and/or thermoelectric devices, internal combustion engines, and human powered devices. This paper explores the viability of each energy source in meeting the soldier's demands.

Currently, the Land Warrior version 1.0 system uses batteries to power its systems. These batteries are heavy and have low specific weights. At best, they can power the entire system for 12 hours without recharge. However, the future energy demands of the Land Warrior system may increase in both average power required and mission duration. It is possible and feasible that other energy sources besides batteries may better attain the power requirements of the Land Warrior systems in the future. Alternative power sources such as fuel cells, micro-turbines, photovoltaics, and thermoelectric devices may have the ability to replace or augment batteries as the power source for the Land Warrior system.

This paper will specify the current, short-term, and long-term viable energy source solutions for the Land Warrior energy supply systems based on user requirements. The requirements that the power sources must meet in order to be used to power the Land Warrior system are many:

- Provide 18 watts of power for a duration of 18 hours,
- Weigh less than 2 pounds,
- Function while submerged under water,
- Possess low infrared signature,
- Low cost,
- Small size,
- Low noise level, et cetera.

## NOMENCLATURE

BDU	Battle Dress Uniform
Card Rdr	Card Reader
Comm Card	Communication Processor Card
Comp Assm	Computer Assembly
CPU Card	Computer Processing Card
DRM	Dead Reckoning Module
DVS	Daylight Video Sight
GPS	Ground Positioning System Card
HHD	Handheld Flat-Panel Display
HIA	Helmet Interface Assembly
HMD	Helmet-Mount Display
I2	Night Image Intensifier
ICID	Individual Combat Identification Device
KBD	Handheld Keyboard
LR/SR	
Adapter	Radio Adapter
LW	Land Warrior
LWTS	Light Weight Thermal Sight
MFL	Multi-function Laser
Mic/Spkr	Microphone/Speaker Assembly
PV	Photovoltaic
STMS	U.S. Army Soldier Tactical Mission System
VOIP	Voice Over Internet Processor
WLAN	Wireless Local Area Network Card
WLAN Ant	HOA/Wireless LAN Antenna
WUI	Weapon User Interface

## LAND WARRIOR SYSTEM

The Land Warrior version of the Soldier Tactical Mission System is composed of numerous systems, including over twenty devices that require electrical energy. The devices are categorized into various subsystems and this paper highlights equipment included in the following subsystems:

- Integrated Helmet Assembly Subsystem,
- Weapon Subsystem,
- Communications Related Subsystems.

Figure 2 is included to show the general location of various subsystems. In the following subsection, each subsystem will be discussed in detail and graphics will be included for clarity.

#### Integrated Helmet Assembly

- Color Modular Display
- LW Assault Helmet
- Night Display (I2)
- Audio System
- Integrated Combat ID



#### Computer/Radio Subsystem

- Computer
- GPS
- Integrated Navigation
- Soldier Radio
- Leader Radio
- Handheld Display

#### Weapon System

- M4 Modular Weapon System
- Light Weight Thermal Sight
- Day Light Video Sight
- Multi-functional Laser
- Personal Area Network
- Other Existing Weapon & Accessories

#### Software Subsystem

- Software

#### Protective Clothing & Individual Equipment Subsystem

- MOLLE
- Interceptor Body Armor
- Other Existing CIE
- Pouch Cell Batteries
- Power Distribution Bus
- MILES 2000



specific and the device is placed in standby mode when stowed.

The Helmet Interface Assembly (HIA) transmits signals from one component to another. The HIA is always powered on with a 2% peak anticipated.

The Night Image Intensifier (I2) is a version of night vision goggles that allow the soldier to see under limited visibility conditions utilizing ambient starlight. Currently this system does not use the Land Warrior power sources (it has internal batteries) and is not connected to the LW communications system. The soldier powers the device up when required and turns the device OFF when not in use.

#### Weapon Subsystem

The Land Warrior's weapon subsystem, shown in Figure 4, includes several electrically powered devices, listed below, as well as the M4 modular weapon system (used to mount interchangeable sensors to the M4 weapon) and several other existing (non electrical demanding) weapon accessories. The devices within the weapon subsystem that require electrical power include:

- Daylight Video Sight (DVS)
- Multi-function Laser (MFL)
- Individual Combat Identification Device (ICID)
- Light Weight Thermal Sight (LWTS)
- Weapon User Interface (WUI)
- Personal Area Network Body/Weapon Hub

The soldier uses the Daylight Video Sight (DVS) during the day when ambient light is sufficient. The DVS device is mounted to the weapon on the M4 modular weapon system discussed above. The image from the video camera is relayed from the end of the weapon to the soldier's eyepiece monitor where the image is displayed. This device allows the soldier to fire around corners or over objects without exposure to the enemy. The image can be transmitted to other personnel to provide an opportunity for enhanced understanding of the tactical situation. Intelligence experts who normally would not have immediate access to front line information can also analyze the images. The DVS is turned OFF manually when not selected for viewing.

**Figure 2 – Various subsystems included in the Land Warrior system.**

#### Integrated Helmet Assembly Subsystem

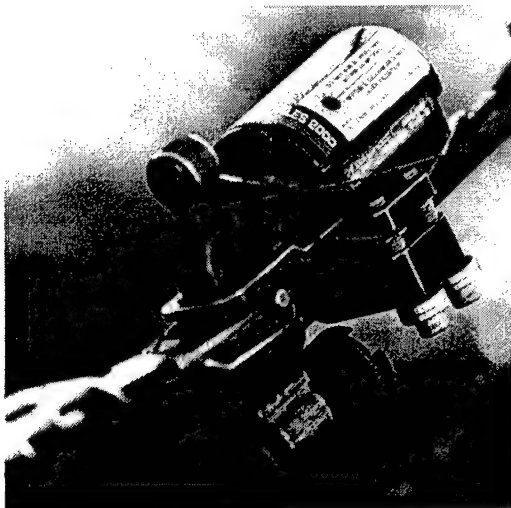
The integrated helmet assembly shown in Figure 3 includes an assault helmet as well as the following electrical powered devices:

- Microphone/Speaker Assembly (Mic/Spkr),
- Helmet-Mount Display (HMD),
- Helmet Interface Assembly (HIA),
- Night Image Intensifier (I2)

Microphone/Speaker Assembly (Mic/Spkr) is the helmet's audio system, which includes both a speaker and a microphone. The assembly allows the user both input/output audio communications.

**Figure 3 – Land Warrior Integrated Helmet Assembly Subsystem**

Helmet-Mount Display (HMD) is a visual (color) display on the soldier's helmet. The display is designed as a retractable eyepiece in order to be repositioned when required. The visual display serves many purposes. It provides input to the soldier from various sensors, such as the video sight, thermal sight, or image intensifier. The images from these sensors are simply obtained by pointing the weapon in the direction of interest. This information is generally used for aiming or visual information purposes. The visual display can also show digital terrain maps enhanced by friendly situational awareness, sector graphics showing defensive and offensive planning measures, orders from higher headquarters, and completed soldier reports. The use of the HMD is mission



**Figure 4 – Land Warrior Weapon Assembly**

The Multi-function Laser (MFL) serves as a range finder, target designator, and spotter. It also includes a digital compass assembly. The MFL allows the soldier to better estimate locations for indirect fire, to indicate targets for others to fire on, and to indicate to others points in the distance to focus attention on. The soldier turns OFF the Multi-function Laser including the digital compass assembly manually when not in use.

The Individual Combat Identification Device (ICID) allows the soldier to identify other individuals on the battlefield as friendly utilizing the multi function laser discussed earlier. This device is under development and may be included within the LW ensemble in the future. The laser can be encoded to interrogate a sensor on an individual soldier and indicate to the sender whether the recipient is encoded correctly. This technology, though not as far advanced as other components of the system, have the ability in the future to establish better situational awareness and reduce incidents of fratricide.

The lightweight thermal weapons sight is used at night or during reduced visibility conditions when thermal imagery is needed. The thermal sight functions like the daylight video sight; however, it can be used in adverse sight conditions such as smoke, fog, and adverse weather conditions. Soldiers can utilize this device to aim the weapon from a protected position and transmit visual information back to commanders. The thermal sight detects much more information than the naked human eye and it can be used to locate personnel in dense foliage or see 'old footsteps' on a building's floor. The lightweight thermal weapon sight currently uses a self-contained battery and the device is placed in standby mode when not in use.

The Weapon User Interface (WUI) allows the soldier to use the weapon while interfacing with a select number of communication related features. The WUI allows this interaction to occur while the soldier maintains direct physical contact with the weapon. For example, with both hands on the weapon, the soldier can select to aim the weapon through the video-thermal sight and then select to transmit the image from the weapon sight to the Land Warrior communication system via the LAN (for local level communication) or through the transmission of a digital image using the radio (for headquarters communication). The WUI is active through most of the mission drawing an anticipated 1% peak power. When not in use the soldier places the device in standby mode.

The Personal Area Network (PAN) Body/Weapon Hub transmits information between the components of the LW systems. The PAN Weapon and Body Hubs are always powered on, with a 2% peak power draw anticipated.

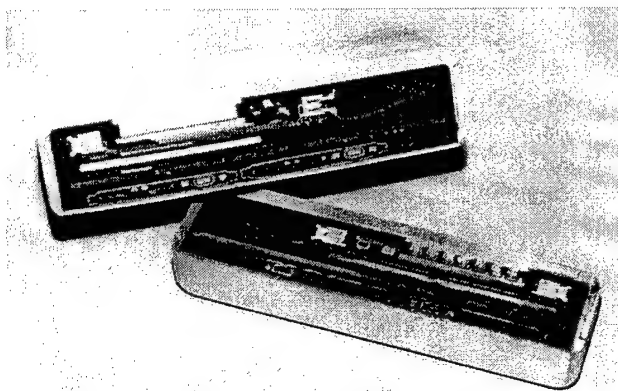
### **Communications Related Subsystems**

The Land Warrior's communications related subsystems include the Communication, Computer, Navigation, and Personal Area Network Subsystems. Many of the devices within these subsystems are packaged and integrated as shown in Figure 5. The following devices requiring electrical power include:

- Handheld Flat-Panel Display (HHD),
- Handheld Keyboard (KBD),
- Computer Processing Card (CPU Card),
- Computer Assembly (Comp Assm),
- Communication Processor Card (Comm Card),
- Card Reader (Card Rdr),
- Wireless Local Area Network (WLAN) Card,
- Voice Over Internet Processor (VOIP),
- Ground Positioning System (GPS) Card,
- Dead Reckoning Module (DRM),
- Radio Adapter (LR/SR Adapter),
- HOA/Wireless LAN Antenna (WLAN Ant).

The Hand Held Flat-Panel Display (HHD) includes a soft keyboard. Only the leader within a small unit possesses the handheld flat panel display. This device provides a hand held screen (or monitor) to view electronic maps, troop locations, and relevant tactical and logistic information. The device is turned OFF and stowed when not in use.

The Handheld Keyboard (KBD) allows the leader to type commands and messages that are then transmitted over the wireless local area network. The leader can use this device to type operations orders, send up reports to commanders, and other varied applications where typed information is more appropriate and effective than voice transmissions. The KBD is turned OFF and stowed when not in use.



**Figure 5 – Land Warrior Integrated Computer Assembly**

The Computer Processing Card (CPU Card) and the Computer Assembly (Comp Assm) are turned on with either the Helmet Mounted Display or the Hand Held Display. These components are the brains of the overall Land Warrior system and analogous to the motherboard on a personal computer. The computer assembly/processing card processes all of the incoming and outgoing information while providing coordination between components. The CPU Card and Comp Assm are placed in standby mode when not in use.

The Communications Processor Card processes communication data from the radio, wireless local area network, ground positioning system, et cetera. This card and the main processing card are similar; however, the communications processing card only serves the communications equipment thus allowing for quicker and more effective communications. The Comm Card is always powered on with a 2% peak power draw anticipated.

The Card Reader (Card Rdr) is used at the beginning of a mission profile to power up the Land Warrior system. It is used for security purposes and future revisions may include various pattern recognition technologies to augment or replace this device. In normal operating mode, the card reader is placed in standby. The Card Reader has a 1% usage rate at the start of any mission profile and it is placed in standby mode otherwise.

The Wireless Local Area Network (WLAN) Card provides a critical local area network for the Land Warrior soldiers. The card serves a function analogous to the modem on a personal computer that allows one user to communicate with another user's computer directly. The Land Warrior wireless local area network card allows the network to function between the many different Land Warrior systems in a tactical unit. The Wireless Local Area Network Card is always powered on with a 2% peak operation anticipated.

The Voice Over Internet Processor (VOIP) is utilized when transmitting and receiving voice radio traffic. The VOIP is always powered on with an anticipated 2% peak operation.

The Ground Positioning System (GPS) Card receives information from a GPS antenna and calculates the precise location of the soldier through triangulation of satellite signals and comparison to digital data elevation files. This information is transmitted to the Land Warrior system

allowing the soldier, as well as higher and adjacent personnel, to know the soldier's location providing increased situational awareness. The GPS Card is always powered on with a 10% peak power draw while acquiring a signal. A backup battery is required.

The Dead Reckoning Module (DRM) augments the GPS system in determining the location of the soldier. A digital compass is utilized along with a pedometer to determine the current location of the soldier from the last known point. This location is then integrated with the GPS determined location through a Kalman filter to provide a more accurate location. The GPS signal is not constantly available due to buildings, terrain, certain atmospheric conditions, or man-made jamming and, therefore, the DRM is an indispensable part of the enhanced navigation system. The digital compass is also used to determine the direction that the soldier is facing. The directional information is displayed on the digital maps as a simple arrow. The Dead Reckoning Module (DRM) is always powered on with a 2% anticipated peak.

The Soldier and Leader Radio Adapters (SR/LR Adapter) are self-powered and use a self-contained 5V battery. These devices are always powered on.

HOA/Wireless LAN Antenna (WLAN Ant) includes a power amplifier. The antenna and power amplifier transmit the wireless local area network information between Land Warrior systems. This is what transmits and receives the electronic information that is passed over the network. This component is not only utilized by the wearer but by other components of the system to retransmit information to those out of reach of the initial signal. The use of the HOA/Wireless LAN Antenna (including the power amplifier) is dependent on the mission profile and the device is placed in standby mode when not in use.

## **SOLDIER ENERGY SYSTEM REQUIREMENTS**

The customer requirements for a Land Warrior energy delivery system are listed in TRADDOC's Operational Requirements Document for Land Warrior (ORD 2001). The listed requirements within this document are categorized in several different manners. Operational capability categories include six areas: overall system, situational awareness, lethality, survivability, mobility, and sustainability. The priority of a capability is categorized as either a key performance parameter (KPP) or a non-key performance parameter (non KPP). The evolution of required system capabilities are categorized as Block I, II, or III. Block I requirements are the "threshold requirements" which establish a fighting, command, and control capability for the light infantry company and below. Block II expands these capabilities to allow the LW system to interoperate with the mounted interim forces. Block III provides the evolutionary link to the United States Army's Objective Force Warrior.

Table 1 summarizes the customer requirements for the LW Power Subsystem. These include information regarding the priority for these requirements and "Block" reference. One customer requirement that is sometimes overlooked is listed as number 7 in Table 1 and pertains to the submergibility requirement of the LW ensemble. Figure 6



shows the LW soldier in an environment that dictates the inclusion of this customer requirement.



**Figure 6 – Land Warrior Soldier in an Aquatic Environment**

**Table 1 – Land Warrior Customer Requirements for the Power Subsystem**

	<b>Customer Requirements</b>
1	<b>RUNTIME (KPP)</b> <b>BLOCK I</b> Provide a system power source with integrated system power management to achieve a system runtime of 12 mission hours. <i>Note: The runtime is increased to 24 hours for Block II and 72 hours for Block III.</i>
2	<b>WEIGHT (KPP)</b> <b>BLOCK I</b> Utilize a power source that weighs 2.0 pounds (maximum). <i>Note: The weight requirements associated with Blocks II and III are anticipated to decrease because of the incorporation of an interim armored vehicle, which may incorporate recharging capabilities.</i>
3	<b>SOURCE TYPE (KPP)</b> <b>BLOCK I</b> Utilize a disposable power source. Rechargeable batteries must have a simple indicator that verifies state of charge. <i>Note: The energy source associated with Blocks II and III is anticipated to change because of the introduction of the interim armored vehicle on the battlefield.</i>
4	<b>RELIABILITY (KPP)</b> <b>BLOCK I</b> The energy subsystem shall possess a 92% probability of operation for 12 hours without incurring a mission affecting failure. <i>Note: For Block III, the leader's energy system shall possess a 93% probability of operating for 12 hours without incurring a mission affecting failure. The</i>

	<i>probability for a soldier is 94%.</i>
5	<b>TEMPERATURE (Non-KPP)</b> <b>BLOCK I, II, and III</b> The energy subsystem will function in the temperature range from -25° F to 130° F (-32° C to 55° C). <i>Note: A winterization kit can be utilized for temperatures below 0° F (-17.4° C) and the kit's weight will not count towards the weight limitations.</i>
6	<b>AIR DROP (Non-KPP)</b> <b>BLOCK I, II, and III</b> The energy subsystem will not be adversely affected by airdrop when worn by an individual parachutist.
7	<b>SUBMERGIBILITY (Non-KPP)</b> <b>BLOCK I, II, and III</b> The energy subsystem will be waterproof to a depth of 3.28 ft. (1 m) and remain operational in salt air and water conditions globally.
8	<b>SOUND SIGNATURE (Non-KPP)</b> <b>BLOCK I, II</b> The energy subsystem will be audibly non-detectable at 49.2 ft. (15 meters). <i>Note: Block III requires that the system will be audibly non-detectable at 16.4 ft. (5 m). In addition, while in silent watch mode, the system will be audibly non-detectable at 3.28 ft. (1 m).</i>
9	<b>SHOCK/VIBRATION (Non-KPP)</b> <b>BLOCK I, II, III</b> The energy subsystem must be capable of withstanding the shock of a soldier in combat and the vibrations associated with transport.
10	<b>PHYSICAL DURABILITY (Non-KPP)</b> <b>BLOCK I, II, III</b> Performance degradation from mud splatters, dirt, or wind-blown sand, dust, or rain will be minimized.
11	<b>MEAN TIME TO REPAIR (Non-KPP)</b> <b>BLOCK I, II</b> The mean time to repair the energy subsystem in the event of failure or malfunction must be less than one hour. <i>Note: For Block III, the mean time to repair is reduced to 0.68 hours.</i>
12	<b>START-UP TIME (Non-KPP)</b> <b>BLOCK I, II, III</b> The complete LW system (including all components) must be operating at normal capacity within 3 minutes of LW system start-up.
13	<b>CHEMICAL DURABILITY (Non-KPP)</b> <b>BLOCK I, II, III</b> The energy sub-system must operate for a minimum of 12 hours in a Nuclear, Biological, and Chemical Environment without contamination or hazardous

	degradation.
14	<b>SAFETY and HEALTH HAZARDS (Non-KPP) BLOCK I, II, III</b> The energy sub-system shall be designed to eliminate or control all potential health and safety hazards to the soldier. Appropriate assessments will be conducted to ensure compliance.
15	<b>ORIENTATION (Expert Knowledge)</b> The energy sub-system must remain operational and fully functional in any orientation.

### **Energy Demand**

Estimating energy demand for the Land Warrior system is a difficult task due to its dependence on several uncontrollable variables. Energy demand is based on usage of the various electrically powered components, and although it is trivial to calculate the energy consumed when the Laser Range Finder is used once, for example, it is difficult to estimate how many times the Laser Range Finder is used in a combat situation. There are three major tools available at this time to attempt to estimate energy demand including subject matter experts, experimentation, and simulation.

Subject matter experts conducted studies in the past attempting to estimate a given mission's energy demand based on how often components are utilized. The analyses are conducted through war gaming a situation moment by moment and recording the results, thus providing very specific data for what may happen in a real world environment. The estimates, however, pertain to a very specific situation, and are highly subjective, undoubtedly different depending on subject matter expert participants. The Operational Requirements Document for the Land Warrior system [ORD, 2001] specifies six mission profiles for which the Land Warrior should be analyzed against, ranging from major combat to peacekeeping operations. Each mission necessitates different actions by the participants and thus different levels of overall LW energy demand. If possible, it is desirable to have more accurate estimates of the actual demand, though this method has given us to date the most reliable data to utilize in planning.

The second option to estimate demand is through real world field trials or experimentation. Field trials of this equipment have been done on a modest scale, the largest being the deployment of a platoon size Land Warrior (version 0.6) equipped force in the Joint Warfighting Experiment in 2000 at the Joint Readiness Training Center at Fort Polk, LA [Caldwell, 2000 and Kinnison, 2000]. Energy usage data collected from this large-scale experiment was a collective estimate of the logistics resupply process given as number of batteries used per mission. While useful from a logistics standpoint, this data does not reveal how much each piece of equipment was used or if more power would have been used if it were available. In addition, the equipment used in the experiment was LW version 0.6 and the version to be fielded in 2003 to the U.S. Army Rangers is LW version 1.0. The differences between the average power draws associated with the versions are significant. Finally, and again, the

experimentation was only conducted against a small subset of potential mission profiles.

The third methodology to find the demand per component is to model this demand through combat simulations. Simulation is often used to assess weapon systems in their development because either the equipment is not fully developed or the cost and time of experimentation against all possible scenarios is prohibitive. Many combat simulations exist which are capable of modeling some facet of the land warrior system – the Integrated Unit Soldier Simulation (IUSS) was developed specifically to model the Soldier Tactical Mission System [Middleton, 1998]. The focus of the simulation is to model the capabilities of the system; for example, the ability to shoot from a protected position can be modeled because the operator has less exposure to enemy fire and better ability to target enemies. In the same way, the effect of more accurate and timely indirect fire from better target location estimation resulting from the laser range finder can be modeled, resulting in more enemy killed and wounded, and subsequently lower enemy personnel shooting back at our forces. The ability of this modeling is limited, however. The model does not, for example, model explicitly the use of the laser range fire, the number of times the trigger is pulled, and the power expended to send out the laser beam and then calculate the position, the power to send that information either digitally or over voice radio.

The output of the combat simulation provides the measurements available from a particular situation. Common metrics are the number of killed and wounded, number of shots by type fired, period of certain actions. Data can be garnered out of the simulation results. For example, if one can determine if indirect fire was used, an estimate can be made as to the number of times a laser range finder was used. Another important issue with this technique is that it provides a mechanism to run multiple simulations, which can be modeled against various scenarios and can vary stochastically to provide statistically significant results.

This last method discussed, which is in reality a combination of simulation results tempered by subject matter expertise, is the method currently utilized to attempt to estimate demand for power by component, and the outcome of that usage.

In the future, there are two things that would greatly improve the U.S. Army's ability to estimate the LW component power demand: 1) more explicit representations of component usage in models, and 2) a data collection capacity in the Land Warrior system that could collect useful statistics for the components while in actual operation.

For the simulation improvement, it would be useful to see increased fidelity in the way LW components are modeled. If the simulation included usage of component information, such as the laser range finder, one could see from scenario to scenario how often the laser range finder was used. This information would allow engineers the ability to back out (or have the simulation provide) the power and energy demands for each component by scenario. Likewise, the other components, such as radio transmissions, would also be recorded. In order to implement this enhancement into the simulation model, the model would also need to make use of

information regarding the effectiveness of the soldier. For example, every time the laser range finder is triggered or the radio is used we do not necessarily benefit, similar to the fact that every time a trigger is pulled it is not a well-aimed shot.

Data collection in the Land Warrior system would serve two major purposes. First, it would allow more accurate data to be collected which would enable a better initial energy management system to be established. Second, the data would also allow for the possibility of developing and implementing a dynamic control policy that would take the current situation and component usage factors into account to make recommendations to control the power usage. By having actual data on component utilization during various mission profiles, a control system could be designed that determined which components were likely to be used in a given mission scenario and power off less crucial equipment in the event that the energy source availability is limited. Various energy management concepts are discussed in greater detail in the next section.

### **Energy Management**

Energy management may prove to be crucial to advances in the capabilities of the Soldier Tactical Mission System. As follow on versions of the Land Warrior are developed (Objective Warrior and Future Warrior) the likelihood of energy demand increase is high. The increased energy demand may also increase capabilities to stay ahead of adversaries. Logistic demands to transport, replace, or recharge batteries place a large burden on the force, and make some circumstances or missions untenable and, therefore, smaller, lighter, longer lasting power sources are desirable.

To create an intelligent energy management scheme for the LW system, four elements are required:

- Accurate information on the amount of power used by each component,
- Accurate information on the amount of energy remaining in the source,
- How much gain results from utilizing a particular component in a particular circumstance, and
- The ability to determine the current mission scenario

If these elements were better understood, the ability would exist to make more rational and nearer to optimal decisions on component utilization as a means to extend energy source supply.

In an emergency where the mission length lasts longer than expected, one solution to the problem of the power shortage would be to shut down certain components of the Land Warrior system in order to conserve power so that the system can stay functional longer. For this reason, shutdown priority lists are under development by subject matter experts in order to provide an order by which components will be powered down in order to extend source life.

In creating these lists, the importance of each LW component to the ability of the overall system to function is taken into account. For example, most of the functionality of the LW system is lost without the computer assembly and the

computer-processing card. In addition, the importance of each of the LW component to the soldier's ability to complete a given mission is also taken into account. Information used here is acquired from interviews and reports from soldiers who tested the equipment [Project Riflemen, 2001] and infantry officers. As one would expect, the preliminary results indicate that the thermal weapon sight and the communication related LW components are the most vital elements of the LW under most mission profiles. The navigational capabilities are determined as next greatest importance.

### **Energy Sources**

Currently the U.S. Army uses batteries to handle the vast majority of its portable energy source and storage requirements on the battlefield. Therefore, the first versions of the LW system also utilize this technology. Batteries are robust in design and provide nearly instant power availability. The progression in battery technology is more evolutionary rather than revolutionary in nature. Currently, batteries remain the leading portable power source in the military for numerous reasons and their presence will inevitably continue for the next several years (at a minimum). Future promising battery technologies include exotic substrates such as Zinc-air.

The current energy source solution for the soldier is the battery, made available for the duration of a given mission. This presents issues of recharging and/or resupply as well as weight, all of which must be addressed. If, however, one were to look at the energy issue outside the battery, then other possibilities present themselves not only from the power point of view but the weight as well. In addition, one should consider systems that do not require fuel and can be self-sufficient that present opportunities, in the short term as well as the long term.

The remainder of this section will explore various feasible energy conversion technologies that could meet the energy supply/storage requirements of the LW system. The first subsection discusses current battery use in the military. The following subsections present various energy conversion systems that utilize an external fuel source, such as the fuel cells and microturbines) as well as self-sufficient energy conversion systems (photovoltaics and thermoelectric technologies.)

### **Batteries**

Generally, primary batteries (disposable) are used in combat scenarios while secondary (or rechargeable) batteries are used during training. Primary batteries have a higher specific energy. Figure 7 includes the batteries required for the LW version 1.0 system and Table 2 shows the evolution of battery utilization from LW version 1.0 to the current riflemen in the U.S. Army. The reduction in battery count and battery type is attributed to the incorporation of a more centralized design concept for power.

### **Fuel Cells and Microturbines**



Fuel cells, microturbines, and other micro-electro-mechanical systems (MEMS) present other opportunities for power generation for the soldier mission. In each, fuel will be required, however. Although fuel cells could provide large amounts of power, microturbines, and other MEMS have a long ways to go to generate the amount of required power. However, the opportunities presented by the microturbines and other MEMS for future systems, power or other, are tremendous and in due time will be able to help solve difficulties that are present today. If one were to look even more into the future, many of the MEMS will be replaced by NEMS or nano-electro-mechanical systems. Those technologies that are in their infancy should be the goal to reach.



**Figure 7 – Batteries Used in Land Warrior V/1.0**

(Courtesy of Mr. Steve Slane, CECOM, Army Power Division of the Research Development and Engineering Center Army Research Lab, Fort Monmouth, NJ, Nov 2001)

**Table 2 – Comparison Between Batteries Required for Land Warrior V/1.0 and Current Riflemen** (Courtesy of Mr. Steve Slane, CECOM, Fort Monmouth, NJ, Nov 2001)

**Land Warrior Version 1.0 Batteries**

Type	Item	#	Weight (Lbs.)
LW System Battery	Land Warrior System (Computer, radio, GPS, dead reckoning module, daylight video sight, helmet mounted display, soldier control module, multi-function laser, thermal weapon sight)	1	2.0
DL1/3N	Close combat optic	1	0.01
AA Alkaline	Night vision goggle	2	0.11
	<b>Total</b>	<b>4</b>	<b>2.12</b>

**Current Riflemen**

Type	Item	#	Weight (Lbs.)
BA5347	Thermal weapon sight	2	1.3
DL1/3N	Close combat optic	1	0.01
AA Alkaline	Night vision goggle	2	0.11
BA5800	Handheld GPS	1	0.7248
AA Alkaline	Aiming light	2	0.11
AA Alkaline	Soldier intercom sys	8	0.44
	<b>Total</b>	<b>16</b>	<b>2.69</b>

Fuel cells are an interesting energy source option for the LW Soldier. The cells typically utilize a hydrocarbon fuel source, such as methane, propane, or methanol. Hydrocarbons combined with air to produce water and electricity (DC). Fuel cells are a reliable DC power source and can be used in conjunction with batteries for battery recharging.

Commercially, this technology is already available in many products including a cellular phone battery charger that uses a fuel cell. The volume of fuel cell is approximately as large as a half pack of cigarettes ([www.electric-fuel.com](http://www.electric-fuel.com)).

Automotive manufacturers are making prototype cars that are powered by fuel cells. There have also been recent developments in using sodium borohydride as a potential fuel source for automotive fuel cells. The sodium borohydride fuel cells may provide similar energy densities as present internal combustion engines. The main advantages of sodium borohydride fuel cells are better fuel utilization and a reduction in throttling. Disadvantages include a pH requirement greater than 12 as well as a high cost due to the use of platinum as the catalyst.

Recently a company in the United Kingdom has developed a hybrid energy system that integrates battery with fuel cell technologies to power portable electronic equipment for the British Army. The device uses a Proton-Exchange Membrane Fuel Cell (PEMFC). The fully integrated battery and fuel cell has a 100-watt, instant power-up capability and the technology has been used to run a soldier communications system.

When comparing batteries and fuel cells, the specific energy densities are vastly different as shown in Table 3. Fuel cells appear to have the potential for advancement, however adequate fuel sources are still an issue that requires resolution.

**Table 3 – Comparison of Specific Energies of Batteries and Various Fuels** (Courtesy of Dr. Deryn Chu, Team Leader Fuel Cell Program, Sensors and Electron Devices Directorate, U. S. Army Research Laboratory, Adelphi, MD, Dec 2001)

Fuel	Specific Energy [kWh/kg]
Hydrogen	33000
Diesel fuel	13200
Methanol	6200
TNT	1400
Battery	Specific Energy [kWh/kg]
Primary battery	500
Rechargeable	200
Alkaline	80
Nickel- cadmium	40

Microturbine technology, although still in its developmental infancy, appears to be a very realistic candidate for energy source production in the extended future. What makes microturbines so appealing? One source is their fuel. Like fuel cells, which use an external fuel supply, the

microturbine is capable of extremely high specific energy (as listed in Table 3). Currently, the Army's most common battery, the BA5590, has a specific energy near 150 kWh/kg. Because microturbines may use hydrocarbons as their fuel, the specific energy may be much greater. For diesel, specific energies of 13200 kWh/kg are theoretically possible. Another advantage is in manufacturing, where semiconductor production technology allows for decreased cost, redundancy, and standardization.

The microturbines potential as a future power source for LW is been recognized and current research at MIT is under way to further explore and advance the technology. The first prototype microturbines have recently been produced through this program. The devices are the size of a shirt button; operate at 2.4 million RPM (approx.); are capable of producing 10-20 W; and possess ten times the energy density of current batteries. In 5 to 10 years, the microturbines should provide 1600 kWh/kg and in the far term, 2300 kWh/kg.

They have a thermal efficiency of 5 to 10%. The efficiency will most likely increase once problems with the 1.5 mm combustion chamber are resolved. Some identified problems to date include high noise levels associated with vibrations that may be resolved with springs and air diffusion as well as super-fast combustion that results in a difficulty-achieving swirl.

Although this technology may replace batteries, as of now it does not seem to save any size. The microturbine itself is very small but the fuel required running it takes up about as much space as current batteries with an overall size of an aluminum soda can at present.

### **Solar Power – Photovoltaic Panels**

Solar power may be feasible, however durability is a concern. Devices uses sunlight to produce electricity however there are some durability issues. Traditionally, single-cell silicon cells produce the highest efficiencies while being extremely expensive to produce. Photovoltaic (PV) arrays have high capital cost (\$/kW) with output depending on solar radiation, array construction, and array size. Semiconductors are used in the PV array's construction, such as continuous type silicon cells, oxidized gallium arsenide, etc. [Sorensen, 1983]. Continued technological advances are expected to result from advances in material development. With these advances, PV technology could augment the traditional sole battery power source on the battlefield. These devices could be used in hybrid systems with fuel cells and/or battery systems.

New amorphous silicon technology may allow the cells to retain durability for military applications while maintaining an effective level of efficiency. A portable PV battery charger has been developed for the military in wattages of 10.5, 15.8, and 30 W while operating at an efficiency of 6.1%. Refer to Table 4 for more performance data. The device is constructed of double-cell laminates that are sewn into military grade, camouflage colored, rip-stop nylon. Tests have shown that the PV array continues charging while being shot through or run over. If 10% of the surface area is damaged, the remaining 90% of the surface area continues to produce useful output.

The typical operating temperature is 140° F (60°C) with minimal losses experienced at higher temperatures.

The outer layer is composed of Tefzel, which is a specially formulated version of Teflon for solar applications. This material is more transparent than glass while also flexible and virtually unbreakable. The PV device uses triple junction silicon solar cells, which are three layers of amorphous silicon that absorb red, blue, and green light. Sunlight first encounters a topic layer of conductive oxide then amorphous silicon alloy, which absorbs blue light then amorphous silicon-germanium alloy which absorbs green light then amorphous silicon-germanium alloy that absorbs red light. Behind this, there is a back reflector and finally a 125 microns thick stainless steel substrate. The active layers including the conductive oxide are less than 1 micron thick.

	UNI-PAC® 10 12V	UNI-PAC® 10 24V	UNI-PAC® 15 12V	UNI-PAC® 30 12V
<b>Rated Power (W)</b>	10.5	10.5	15.8	30.0
<b>Operating Voltage (V)</b>	17.6	35.2	17.6	17.6
<b>Operating Current (A)</b>	0.6	0.3	0.9	1.7
<b>Open Circuit Voltage (V)</b>	26.0	51.9	26.0	26.0
<b>Short Circuit Current (A)</b>	0.74	0.37	1.11	2.1
<b>Folded Size L, W, H (in.)</b>	4.8, 2, 5.5	9.8, 2, 5.5	9.2, 3.1, 5.5	16.9, 2, 7.1
<b>Weight (lbs)</b>	2.1	2.1	3.25	4.7

**Table 4 – Military PV Panel Performance Data**

(Electrical specifications (± 10%) are based on measurements performed at standard test conditions of 1000 W/m<sup>2</sup> irradiance, Air Mass 1.5, and cell temperature of 25°C., more info at <http://www.uni-solar.com>)

### **Thermoelectric/PV Conceptual System**

A conceptual thermoelectric/PV system does not require an external fuel source and can be self-sufficient. The system includes photovoltaic power generation coupled with a built-in thermoelectric cooling-heating option and a storage system that includes batteries for "dark" times. Such a system would not depend on any fuel or external recharging stations and at the same time, it could offer the soldier a certain level of comfort. In view of the fact that the soldier is in different and usually in undesirable climates, the comfort that can be integrated into the system may prove to be a desirable feature.

Until recently, the photovoltaic surface area associated with the required energy of the LW system presented difficult issues to overcome. However, very recently there have been significant advances towards the development of soldier specific PV technology. Industry has been able to come up with PV cells that can be woven into the Battle Dress Uniform (BDU) of the soldier. Refer to Figure 8 for a photo of a soldier in BDU. There are, of course, inherent difficulties associated with this approach. However, strides are underway to resolve some of these issues. One such development is to encapsulate in flexible polymer encasings the woven photovoltaic cells that would also breathe well. To this end, a recent three-year contract (\$1M/year) has been issued to a textile manufacturer that will permit detailed development of such systems. This development may provide a sound proof-of-concept that could lead to further studies in optimum performance, etc.

Concurrent to this development, information from the physiological-medical community could be assembled to determine the most appropriate locations on the human body where "cool" and "warm" feelings would be advantageous. At these locations, thermoelectric coolers/heaters could be placed. With a few degree temperature difference ( $^{\circ}\text{C}$ ) obtained using thermoelectric coolers/heaters (placed appropriately), the soldier's comfort would be improved. The requisite robustness of the system would also need to be studied to ensure continuous operation.

Since there will be "dark" times in power generation, the required power must be available in storage. This could be accomplished by recharging batteries as the power is generated by the photovoltaic BDU system. The number of batteries required, their capacities and discharge/recharge capabilities would have to be identified and satisfied so that the soldier is at no time left without the power needed to accomplish the mission. The interfacing of power generation

and recharging needs to be worked out without any deficiency so that there will be available power at all times.

**Figure 8 – Soldier Dressed in Battle Dress Uniform (BDU)**

Photovoltaics present opportunities to generate the required power for the soldier. The successful developments in BDU collection system, the integration of the thermoelectric modules for comfort, and the recharging of batteries for "dark" times are relatively straightforward work that can be accomplished with the existing technologies that industry is using now. Appropriate contacts will be made to present "proof of concept" for the system so that developments can be accomplished in due time. This integrated system must also reduce the overall weight that batteries alone create for the soldier. Thus, a weight reduction with a no fuel power system can be developed to accomplish the given mission.

## CONCLUSIONS

This paper's intent is to introduce to the interested reader the general problem surrounding the design of an adequate energy supply/storage system for the Land Warrior soldier. In order to introduce the problem, the authors first describe the Land Warrior System, including a synopsis of the various energy consuming devices carried by the Land Warrior soldier. Next, a detailed table is presented that summarizes numerous customer requirements associated with the design of a viable energy supply/storage system. The customer requirements must be translated into engineering requirements, which can then be used in the design the energy supply/storage system.

The issue of energy management is explored in order to expose to future researchers an area requiring significant effort. The final portion of the paper discusses various potential energy supply/storage solutions. Currently, batteries are the most effective power source for the Land Warrior system. Battery technology has been developed over the years and is a very mature technology. The infrastructure currently exists within the U.S. Army for battery use, and therefore a change in the power source/storage technology utilized will translate into significant changes in battlefield logistics.

As research and development activities continue, energy supply/storage systems that require external fuel sources (such as fuel cells and micro-turbines) may provide tremendous benefits to the Land Warrior soldier. In addition, energy supply/storage systems that are self-sufficient and do not require external fuel sources (photovoltaics and thermoelectricity) may also provide tremendous benefits. Both types of systems need to be further explored and perhaps the final solution(s) to the Land Warrior energy problem will be systems that combine several of the technologies presented in this paper.

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# **Chapter 3: IEEE Systems and Information Engineering Design Symposium Paper: Power Management for the Land Warrior System**

The model addressed in this paper, and data resulting from the runs, is included in Appendix B.

# POWER MANAGEMENT FOR THE LAND WARRIOR SYSTEM

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## ABSTRACT

The Soldier Tactical Mission System (STMS) requires power to operate, and as the system becomes more advanced it requires even greater power. Currently this power is provided by a consolidated battery pack. This system must be able to manage the power in a way which is advantageous in the environment they are operating in – whether peacekeeping operations or war, in fog or night, in a jungle or a city. The architecture which determines this decision must be fed inputs as to what components provide what value under those circumstances. This research examines this issue with emphasis on the modeling of capabilities of the system with an agent based model to measure not only the value of components but the synergy created by two or more components.

## 1. INTRODUCTION

The U.S. Army future Land Warrior (LW) system consists of 21 separate components that require power. Unfortunately, current technology in power storage is not sufficient for sustained operations with the system. Available batteries are either far too large, or contain far too little storage capacity to supply the LW with the power required for most missions. An alternative to improving battery technology, is power management. By

developing a power management architecture that recognizes current conditions and mission needs, and then makes a decision on whether each component should be turned on or off, we could prevent the LW soldier from incurring extra weight and contribute to his survivability and endurance on the battlefield. The objective of power management is to use the minimum amount of power by using it only when it is necessary and most efficient. The measure of effectiveness with power management is energy utilization. In order to determine energy utilization we must know two things: 1) How much power does each component use; and 2) how valuable is the use of that component to the soldier. Both of these issues are complex – the first being a function of how often the component is utilized in various circumstances, the second provides an even greater challenge because this equipment is for a large part new to the inventory and extensive field trials are not available. We will focus on the second issue – that of value provided by component.

## 2. METHODOLOGY

Several issues had to be worked through before we began our modeling – the first of which was an exploration of Land Warrior / Soldier Tactical Mission System equipment descriptions to determine what equipment we should use as a basis for our investigation. As much of this equipment is under development, it is not clear what the final issued version of Land Warrior will entail. Some of the basic components have remained fairly constant, but each version differs in some aspect, and as technology advances so do the possibilities for future enhancements. We have selected components of Land Warrior that we feel are likely to be fielded

with Version 1.0 of the equipment, and which we had enough specificity to allow modeling of their capabilities.

Another major shortcoming in our ability to model Land Warrior is that the equipment is largely information centric. The sensors and communications systems involved play a large role in the expected outcome of the use of equipment. At this time that cannot be modeled accurately with standard physics based models – we have to get inside the head of the soldier and allow his decisions to affect the outcome. Research has been conducted on the individual items of equipment utilizing these models – and while it may accurately affect the specific scenario portrayed – we feel that what is primarily lacking is the probability that a scenario would unfold if the soldier on the ground were making the decision. Our research team therefore decided to utilize Agent Based Models to replicate the LW system.

Agent Based Models are founded in the concepts of complexity theory. Individual agents make actions based on a set of pre-defined parameters. Each agent makes decisions independently, based on its current state, environment, and decision logic. The result of this methodology is that small changes in parameters can cause large and unpredictable effects in the outputs – a well known characteristic of Chaos theory. This appears well suited to combat simulation because the battlefield is such a complex and often unpredictable environment. Seemingly minor choices on individual levels can mean the difference between victory and defeat – to cite one of many examples consider the Bayonet charge of the 20<sup>th</sup> Maine at Gettysburg led by Colonel Chamberlain – the bravery, and wisdom (some would say desperation) had a dramatic effect on the outcome of a battle. There are many unquantifiable human attributes that have the potential to greatly affect a battle outcome, and physics based models cannot include their effects – but Agent Based models have the ability to at the least work in that direction by allowing influences to soldier action by implementation of stochastic rule sets.

### **3. BACKGROUND**

The Land Warrior (LW) program is the first stage in the development of the Soldier Tactical Mission System (STMS), which will evolve along with the Objective Force for the next 15-30 years. The LW system is designed to enhance the battlefield capabilities of Infantry soldiers and small

combat units. It integrates a variety of sub-systems and components into a cohesive system that will give soldiers an overwhelming advantage in close combat by giving them, among other things, the ability to understand their environment and harness reach back capabilities for intelligence analysis and fire support. Land Warrior augments the combat foot soldiers ability to shoot, move, and communicate by harnessing technologies for employment on the battlefield.

For our analysis we will focus on eight essential components of the Land Warrior system. These systems are [Bailey]:

#### **3.1 Thermal Weapons Sight (TWS)**

The AN/PAS-13 TWS is an infrared weapons sight that allows the soldier to engage targets in low-light and adverse weather conditions. It has digital video output making it compatible with the digitized Land Warrior.

#### **3.2 Multi-functional Laser (MFL)**

The MFL will provide range-finding, laser designating, and high-density profiling capabilities to the Land Warrior.

#### **3.3 Daylight Video Sight (DVS)**

The DVS relays images from the soldier's rifle to his head display. Among other capabilities, the would allow the Land Warrior to fire from a reduced exposure position.

#### **3.4 Night Optics**

Allow the Land Warrior to see and operate in low light environments.

#### **3.5 Dead Reckoning Module and Global Positioning System (DRM/GPS)**



Dead Reckoning Module and Global Positioning System (DRM/GPS): The DRM provides the Land Warrior with integrated navigation capabilities, and when combined with GPS, it provides precise information on location and movement progression.

### **3.6 Digital Map Display**

Integrated into the Land Warrior helmet subsystem, the digital map allows the soldier to upload, send, and receive graphics in a graphical user interface. This provides the soldier with information on friendly and known enemy unit locations, improving the distribution of battlefield intelligence.

### **3.7 Radio**

Land Warrior's radio subsystem provides improved encryption and gives the soldier with the ability to communicate graphical as well as verbal information.

### **3.8 Individual Combat ID for the Dismounted Soldier (ICIDS)**

By using a laser interrogator and transponder, ICIDS enhances target identification and situational awareness for the Land Warrior. The system should greatly reduce the possibility of fratricide.

## **4. Needs Analysis and Scenario Description**

Developing useful and efficient power management for the Land Warrior system requires that we determine which components are the most valuable in battlefield operations. This depends on the situation the soldier is in. Different missions envelop a wide array of tasks and tactics, so a component that is valuable in Mission A may not be as valuable in Mission B. Different missions also require different

operational times, therefore varying the rate at which the LW can draw power and still have enough left to accomplish the mission. The analysis of Land Warrior to support power management goals must therefore be conducted in the six general tactical scenarios outlined in the Land Warrior Operational Requirement Document [ORD]. These scenarios are:

1. MOUT (Military Operations on Urban Terrain) Attack
2. MOUT Defense
3. Night Attack
4. Hasty Defense
5. Rear Area Operations
6. Stability and Support Operations

For our purposes we selected one of these environments, and developed a base scenario which we could examine the usefulness and validity of different models, and the effects of changes in model parameters on measures of effectiveness (MOEs).

The scenario we chose to use is a simple assault on an objective. In the scenario, the friendly unit (BLUFOR) travels over varying terrain to reach on objective occupied by enemy soldiers (OPFOR). In route to the objective, the BLUFOR soldiers encounter enemy fire from an OPFOR sniper. BLUFOR must successfully bypass or destroy the sniper position, then proceed on route, destroy the OPFOR soldiers and occupy the objective. BLUFOR has artillery support available throughout the scenario. This particular scenario was developed from a field experiment of Land Warrior equipment at the Joint Readiness Training Center in Ft Polk Louisiana in 2002 [Kinnison].

With this model, we want to determine the combat value of different components of the LW system so we can compare value versus power consumption for each component. Once we establish the value of each component, we can then (in future work) maximize combat value given an available amount of power by controlling



which components are fully operational, which components are in stand by, and which are turned off.

## 5. Land warrior capabilities

In researching the different simulation models at our disposal, we found that we would not be able to incorporate components of the LW system directly. Instead, we have to change model parameters to reflect the capabilities that each component affords. We determined eleven different combat capabilities that we can include in our analysis of these components. These capabilities can also contribute to proxy capabilities such as improved calls for artillery, fratricide reduction, and movement and mission speed:

1. Send/receive remote access of sensor data (Radio, Digital Map, ICIDS)
2. See better in limited visibility (TWS, Night Optics)
3. Send/receive voice communications (Radio)
4. Send/ Receive digital data (Radio, Daylight Video)
5. Determine location more accurately (DRM/GPS, Digital Map)
6. Send/receive digital graphics (Digital Map, Radio)
7. Know friendly force locations (ICIDS, Digital Map, Radio)
8. More quickly and accurately estimate enemy locations (MFL, DRM/GPS)
9. Fire from reduced exposure position (Daylight Video)
10. Combat identification system (ICIDS)
11. Laser designate/spot target or locations (MFL)

In light of this information, we had to carefully select a model platform that meets a wide array of requirements. We decided that it would be beneficial for our model to incorporate several features. First of all, we want to be able to model situational awareness on the battlefield. This includes the ability to model awareness of both friendly and enemy locations, as well as model soldier behavior upon enemy contact. Next, we identified a need to be

able to model communication on the battlefield, including normal two-way communication and multiple channels of communication for unit leaders. Lastly, we need to be able to model improved firepower and accuracy. In order to model variations in indirect fire we have to be able to alter the time between a call for and the artillery's fire for effect. We also desired a model in which we could change the accuracy of artillery fire. We want to avoid directly changing the probability of kill ( $p(k)$ ) of direct fire, as this could skew the model output in favor of the Land Warrior system.

## 6. Model Selection

We considered using several different agent based models, and finally elected two candidates for the Land Warrior problem which each have various advantages and drawback. First, we looked at the model Socrates, developed by L-3 Communications for Project Albert of the United States Marine Corps. Socrates is useful because it allows us to incorporate multiple communications channels, provides three different levels of leader/subordinate relationships, and utilizes mission logic, that while difficult to use, harnesses three different types of agent movement: Travel, Search, or Vector. We found these modeling capabilities useful for modeling differences in the LW radio, as well as some aspects of situational awareness and calls for indirect fire. However, the agent movement logic does not always seem to work correctly, and there is no way to directly model artillery. In addition the model lacks LOS (line of sight) calculations or terrain capabilities, and when the agents run into the obstacles which the program provides, they lack the ability to move around them and just freeze in place. This makes it very difficult for us to be able to model the DRM/GPS, Digital Map, or artillery capabilities.

The other model we considered, and ultimately chose to use, was MANA, developed by Dr Michael Lauren for the New Zealand Defense Ministry. MANA is advantageous because indirect fire is built

directly into the program and it utilizes more intuitive movement logic, with use of agent "objectives" and "waypoints". It provides us with the ability to incorporate obstacles, terrain, and LOS, and agents can share "awareness maps" that indicate the location of enemy threats. MANA also has a powerful feature that allows one to use "trigger states" which change agent characteristics in the middle of the simulation when one of several specified events occur. These advantages are suitable to our needs to model artillery, Digital Map, DRM/GPS, and improved optics capabilities. Yet MANA also has its own drawbacks. The model only allows agents to use one communications channel each, and the sensor logic is difficult. Therefore, it is less desirable for modeling radio capabilities and leadership aspects. Furthermore, experiments in MANA take much longer than in Socrates, because they currently must be run on a computer cluster rather than a supercomputer (MANA is written in Adelphi, rather than a Unix based language). Whereas we can obtain tens of thousands of runs in Socrates in a few hours from the High Speed Computing Center in Maui run by the US Air Force, it takes several days to weeks to run the same number in MANA (again in Maui).

We Decided that MANA provided an overall more complete package with which to model the Land Warrior system. MANA uses color coded teams to represent different sides in the model. Agents of the same color belong to the same team. For the base scenario, we used blue to represent the friendly forces, which we will call BLUFOR, and red to represent the opposing forces, or OPFOR. We used a map of an operational area in Eastern Europe which was quite rugged as terrain in the model. BLUFOR begins in the a vicinity on the Southern edge of the map, and proceeds to the OPFOR occupied objective in the

Northwest corner. The OPFOR sniper is located between the forces, with BLUFOR artillery located in the Southwest corner. (See Figure 1).

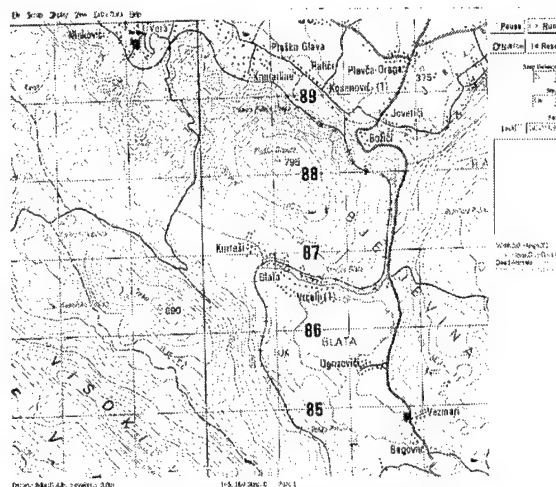


Figure 1: Base Case Scenario in MANA

## 7. DESIGN OF EXPERIMENT

Once we had chosen MANA, and built our base case sniper scenario, we chose several parameters, changes to which could represent different capabilities of the LW system and alter the situational awareness and movement of the agents. The goal of this first experiment was to determine which parameters have the greatest effect on the model's outcome, including the effect of some of the movement parameters. Our measure of effectiveness for this experiment was the number of OPFOR casualties (RedCasualty). The results of the experiment could lead us to a better understanding of the usefulness of MANA as well as provide a basis for experimenting with individual capabilities and components of the LW system.

1. Comms Delay: The amount of time it takes BLUFOR soldiers to transmit a message or other data over radio.
2. Alive Enemies: A number between -100 and 100 that reflects a BLUFOR soldier's aversion (-) or attraction (+) to OPFOR soldiers.

3. Easy Going: A number between -100 and 100 that reflects the BLUFOR's preference for terrain that allows quicker movement.
4. Sensor Range: The range at which BLUFOR soldiers can "see."
5. Movement Speed: The rate at which BLUFOR soldiers move.
6. Cluster: Whatever this number is set to, BLUFOR soldiers will tend to remain in groups of at least this size.
7. Combat: BLUFOR soldier do not want to attack unless they outnumber OPFOR by at least this number.

We used a process called Data Farming [Horne] to collect data on the runs. This process takes, as inputs, which parameters the designer wishes to changes, how much each step is different from the previous value of the parameter, and the range of values by which to change the parameters. For example: Parameter A, 0-100, step by 20 would run Parameter A at values of 0, 20, 40, 60 ,80, and 100. The benefits of data farming are that we can vary many parameters over a wide range of values with relative ease. The problems is that we get a huge data set that is difficult to work with, and some of the most interesting parameters cannot be farmed (because of the design of the model interface at the computing center in Maui). Table 1 gives the parameters, values, and steps we used in this set of runs. Each unique combination of parameters constitutes one excursion. Our experiment consisted of 34,560 different excursions. Running the simulation only ten times for each excursion, using a different seed for each run, gave us a total of 345,600 runs and data points. The reason for the small number of runs was the time required to be devoted at the computing center, and as this work is experimental we felt breadth in parameters instead of depth in a few parameters would serve us more fully. Our next set of runs will focus more directly on parameters we now identify as more significant and conduct a larger number of runs.

Table 1. Parameter Values used in Data Farming

<b>Farming Grid</b>			
<b>Parameter</b>	<b>Range</b>		<b>Step</b>
Comms Delay	5	30	5
Alive Enemies	-25	50	25
Easy Going	-25	50	25
Sensor Range	10	50	10
Mvmnt Speed	50	100	10
Cluster	0	3	1
Combat	0	4	2

## 8. Data Analysis

Because of its monolithic size, it was difficult to perform analysis on the data set. It was too big for most spreadsheets and statistics programs, so we concatenated the data and analyzed the mean of the runs for each parameter set. This gave us mean values for all the MOEs and narrowed the data set down to 34,560 points. This new set was small enough to be handled by all our analysis tools.

We used the statistical software package, MINITAB v. 13, for the bulk of our calculations. We regressed the results, including first order interactions. We conclude that the parameter with the greatest effect on the RedCasualties MOE is Sensor Range, with an R-squared value of 49.4%. The only predictors that seemed to have any effect on their own were Sensor Range, Comms Delay, and Movement Speed. Table 2 includes the R-square value for each individual parameter. Most of the parameters do not appear to have much effect alone.

Table 2. R Square Values for each Parameter

Parameter	R squared value
Sensor Range	0.494
Comms Delay	0.08
Mvmt Speed	0.006
Alive Enemy	0.001
Combat Constraint	0.0001
Easy Terrain	0.000003
Cluster Constraint	0.000000009

There are several interactions that do seem to have a small effect on the output. Four of them include interactions with Sensor Range: Movement Speed, Alive Enemy, Cluster, and Combat. The other one is the interaction between Comms Delay and Movement Speed. We plan in the future to develop the interaction effect analysis more completely.

All of the parameters and their interactions have p-values close to 0. This is largely a reflection of the fact that our sample size for each excursion was only 10. In the future, we will plan to submit at least 100 runs for each excursion so that our results will be more significant. In order to do this, we will have to submit less ambitious experiments and farm fewer parameters.

The fact that sensor range has a so much higher effect on the number of OPFOR killed can be attributed to several factors: 1) BLUFOR sees the sniper earlier, so attempts to bypass and more BLUFOR soldiers reach the objective alive; 2) Since BLUFOR senses OPFOR earlier, the OPFOR soldiers can make better decisions as to how to deploy against the OPFOR soldiers; and 3) Since BLUFOR sees the enemy sooner, the soldiers have more time to call in artillery fire.

The slight effect by the Comms Delay parameter can also be attributed to a couple of factors: 1) The less time it takes BLUFOR to call in artillery, the more indirect fire they can put on OPFOR; and 2)

The less time it takes BLUFOR soldiers to communicate to each other, the quicker they can support each other. That movement speed having a little effect makes sense also, since the soldiers can traverse the dangerous terrain open to the sniper quicker.

We Also conclude that the Combat, Cluster, Easy Going, and Alive Enemies parameters have no significant effect on their own, They show some effect when combined with sensor range, but this may be due more to the sensor range factor than to the actual interaction. Further analysis may be necessary.

## 9. Future Research and Conclusions

The next step in our LW research efforts will be to resubmit experiments that model particular changes in the capabilities of the BLUFOR. This will allow us to submit smaller experiments while allowing for more runs per excursion. The challenge will be to pair the right parameters with the right capabilities and components. After we analyze each component individually, we can then look at combinations of components. Eventually, we will want to repeat this process for each of the six different scenarios we identified earlier – which will also required more advanced scenario generation. We will then use the outputs of the experiments to attach a value to each component. Following this, we can begin a true analysis of power management for each scenario and produce a management system that maximizes combat effectiveness while staying within the limits of total power consumption.

We have found that Agent Based Models provide us with a means of examining the capabilities of some components of the Land Warrior system. The framework we have put this in – of modeling capabilities by varying parameter values in an Agent Based Model – shows

promise, but has not resulted in the focused analysis we presently need to further our research.. The consequence is that we will most likely end up having to either use several different models to solve the problem or develop an entirely new model tailored to the needs of the LW problem. Nevertheless, the research we have conducted thus far should provide a sound basis for further research in the area and a data point in the search for a solution to the to the LW power problem.

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## Chapter 4: Conclusions

This work contains the initial problem definition and modeling in support of the analysis required to develop a power management logic module. We have formulated a scenario, small in scope, and analyzed the capabilities of the Land Warrior system utilizing Agent Based Models. This technique has suggested that while ABMs can model this system the fidelity of the models does not allow us to capture component utility values. The ABMs do suggest that the highest payoffs come from the sensor and communications capabilities. Once utility values for components can be obtained from more realistic scenarios tradeoffs can be made in the selection of power usage under limited availability. This modeling is much more complex because we are not so much comparing components of the system as we are comparing possible combinations of those components, greatly expanding the state space of solutions.

Sensor range appears to have one of the most critical impacts on the system. The Daylight Video sight, the Thermal Weapon sight, and the night vision goggles all enhance the ability of the soldier to sense his surroundings. These components influence the way the soldier acts as well as his ability to affect those surroundings by immediate fires. The decisions the soldier can make are as important as his ability to range a target – in many scenarios bypassing a conflict may well provide victory, and the knowledge of enemy and friendly actions is crucial.

The way ahead for this analysis is to first further refine the scenarios in which to conduct the analysis. Today's soldiers must operate in many environments – and the measures of evaluation we wish to optimize are different between a peace-keeping operation and large scale combat, and have variations in between. Once scenarios are developed ABMs can be used to identify critical combinations of components, and higher resolution models can be used to identify specific utility values for the components and combinations of components. From these utility scores an optimization model can be developed, likely in the form of a dynamic mathematical program, which can determine which components should be used in varying situations and power conditions.

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## Appendix A: List of Abbreviations

A	
ARL	Army Research Lab
B	
BDU	Battle Dress Uniform
BLOS	Beyond Line of Sight
BLUFOR	Blue (Friendly) Forces
C	
Card Rdr	Card Reader
Comm Card	Communications Card
Comp Assm	Computer Assembly
COP	Common Operating Picture
CPU Card	Computer Processing Card
D	
DRM	Dead Reckoning Module (DRM)
DTIC	Defense Technical Information Center
DVS	Daylight Video Sight
G	
GPS	Global Positioning System
H	
HHD	Hand Held Display
HIA	Helmet Interface Assembly
HMD	Helmet-Mount Display
I	
I2	Image Intensifier
ICID	Individual Combat Identification Device
K	
KBD	Keyboard
L	
LAN	Local Area Network
Laser Halo	Laser/Directed Energy Detectors
LOS	Line of Sight
LR/SR Adapter	Leader Radio / squad Radio Adapter
LTWS	Lightweight Thermal Weapon Sight
LW	Land Warrior
M	
MFL	Multi-function Laser
Mic/Spkr	Microphone/Speaker Assembly
MOUT	Military Operations in Urban Terrain
N	
NLOS	Non-line of Sight



NVESD	Night Vision and Electronic Sensors Directorate
O	
OPFOR	Opposing Force
ORCEN	Operations Research Center
P	
PEO	Program Executive Officer
S	
SA	Situation Awareness
SE	Systems Engineering
SEDD	Sensor and Electron Devices Directorate
SEDP	Systems Engineering Design Process
STMS	Soldier Tactical Mission System
T	
TWS	Thermal Weapon Sight
U	
UAV	Unmanned Aerial Vehicle
UGS	Unattended Ground Sensor
UGV	Unattended Ground Vehicle
USMA	United States Military Academy
VOIP	Voice over Internet Processor
Weap Hub	Weapon Hub
WLAN Ant	Wireless LAN Antenna
WLAN Card	WLAN Card
WUI	Weapon User Interface

\*This table is sorted alphabetically

## **Appendix B: MANA Model and Data**

(The model and data are included on a CD inside the back cover)

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